Advanced Robotic Search

Tuan B. Nguyen
Naval Explosive Ordnance Disposal Technology Division (NAVEODTECHDIV)
2008 Stump Neck Road
Indian Head, MD 20640-5070
Phone: (301) 744-6850 Fax: (301) 744-6947 E-mail: nguyent.eodtc@eodmgate.navsea.navy.mil

Subramanian Venkat Shastri
SRI International
333 Ravenswood Avenue
Menlo Park, CA 94025-3493
Phone: (650) 859-5835 Fax: (650) 859-5510 E-mail: venkat@erg.sri.com

Allen Mann
Apple Aid, Inc.
Amherst, NY 14226
Phone: (716) 832-4600 Fax: (716) 832-4610 E-mail: amann@appleaid.com

Howie Choset
Department of Mechanical Engineering, Carnegie Mellon University
Pittsburgh, PA 151213
Phone: (412) 268-2495 Fax: (412) 268-3348 E-mail: choset@cs.cmu.edu

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LONG-TERM GOALS

The long-term goal of this project is to develop and test a small, legged, mobile robot by using Electro-active Polymer Artificial Muscle (EPAM) technology for actuation. In general, the handling of Unexploded Ordnance (UXO) is a problem of particular importance to the Navy, primarily due to the extreme dangers inherent in the use of EOD personnel to neutralize or render safe hazardous items. Of less importance is the fact that the use of humans tends to increase the time to mission completion, due to fatigue and other factors. In response to such concerns, several Navy programs have been initiated. Of these, in the long term, the remote handling of UXO by cheap, expendable robots appears most advantageous in terms of reduced risk to humans and cost-to-benefit ratios.

Significant challenges are present in the development of UXO-handling robots. From the design and development of platforms that negotiate sandy beaches, surf zones, forested or heavily vegetated areas, or rugged terrain, to the design and development of sensing systems that detect and classify mines and other UXO, a number of engineering and computing problems must be solved. The proposed effort is an important first step towards building small, lightweight, high-mobility UXO-handling systems.

OBJECTIVES

The objective of this project is to build and test a legged robot that roughly has the dimensions 3 in. $\times$ 3 in. $\times$ 2 in by incorporating artificial muscle materials combined with improved control methodologies. This size demarcation is important, since at this scale the direct integration of commercially available off-the-shelf (COTS) technologies begins to break down and technology voids in actuation, sensing, computation, and power emerge. The proposed effort addresses technology voids related to the actuation and control of small robots: in particular, the application of SRI's EPAM technology to actuate a legged robot, and biologically motivated approaches to control it. The system will have the necessary batteries on-board for the actuators, but will receive control commands across a data tether from a host PC that will perform all the control computations. The system's target active mission duration will be 20–30 minutes. To achieve this, the following technical objectives are considered:

1. Select legged robot kinematic design. Fabricate robot structure.
2. Design, fabricate, and characterize EPAM actuators for legged robots.
3. Evaluate control approaches for the gait control of walking robots.
4. Integrate artificial muscle actuators and controllers into the robot structure.
5. Test and demonstrate mobility characteristics of robot.
6. Demonstrate mission effectiveness for the mission duration.

In addition to SRI's effort, Carnegie Mellon University's (CMU) objective is to develop coverage path planning for detecting submunitions for outdoor mobile robots. Most coverage-path planners are rudimentary, at best, because they rely on heuristics. As a rule of thumb, heuristics cannot provide any guarantees. The proposed work develops complete techniques, ensuring that the detector passes over all points in the region. The guarantee of completeness removes a potential source of uncertainty that the robot has done its job thoroughly, which is essential in applications such as minesweeping.

Apple Aid's objective is to develop a method for determining the position and pose of UXO relative to a mobile robot using computer vision.

APPROACH

Although the proposal focused on the development of a hexapedal robot, SRI felt it would be best to conduct a quick review of other design options before the basic morphology (number of legs and number of joints in each leg) was finalized. The artificial materials and the actuator configurations are important parameters influence the performance of the legged robots. Their approach to the evaluation of these configurations is based on the performance of a trade-off between system stability, system mobility and system control complexity.

Several parameters influence the selection of actuators for legged robot systems. These are specific energy, speed of response, energy efficiency, controllability and mechanical impedance. No single actuator technology excels in all parameters. Therefore, the selection of actuator technology is necessarily a compromise. For example, shape memory alloys are capable of extremely high specific energy density but are relatively slow to respond, energy inefficient, and difficult to control. By analogy with biological creatures, muscle-like actuators should facilitate the implementation of control algorithms that allow for robust motion in unstructured environments. SRI's Electroactive Polymer (EAP) technology is similar to the performance of natural muscles. It is thus considered a good candidate for the proposed application.

Legged robot control architechure is another important parameter when designing these actuators. Based on biological system control behaviors, the connection between gait models and motor control is related to how Central Pattern Generator (CPG) signals stimulate various muscles. Within a system's theoretic framework, they can be interpreted as one of the following three control methods: direct control, indirect control, and mixed direct-indirect control. SRI has based their architecture development efforts on an indirect control approach. The primary reason for their choice is that it allows a degree of decoupling between the synthesis of leg movement controllers, and gait switching and tuning. In this architecture, gait models are treated as reference models in a control system. The controllers will be designed so that the transfer function between the reference inputs to the models and the compliant motion of the robot's legs is close (by an appropriate metric) to that between the reference input and the reference model outputs. Gaits may be switched and tuned by switching and tuning reference models on line to adapt to changes in the terrain. To validate the architecture, SRI has already conducted a number of control simulations and studied its performance. The results thus far indicate that the architecture has considerable potential for controlling legged robots.

Another challenge is detecting UXOs on the ground and attempting to pick them up. Presently, Apple Aid, Inc. is developing a method for determining the position and pose of UXO relative to a mobile robotic manipulator using computer vision and tactile feedback. The information gleaned from this method will be used to guide the robot in picking up the UXO. In order to clear UXO, the robot must be able to identify it and determine it's position and orientation with sufficient accuracy to allow the robot to pick it up. The position and pose information will be used to guide the manipulator in picking up the UXO, the tactile sensors on the manipulator will determine the distance between the UXO and the manipulator end.

In addition to the above efforts, CMU is curently developing coverage path planning for detecting submunitions for outdoor mobile robots. To ensure complete coverage, this work employs a cellular decomposition, which divides the target region into subregions, called cells, such that simple back-and-forth motions, like that of an ox plowing a field, suffices to cover the cell. The planner achieves complete coverage simply by ensuring that the robot identifies and visits each cell in the region. Prior work includes developing a decomposition called the boustrophedon decomposition and this effort has developed a procedure to implement the boustrophedon decomposition in an unknown environment, i.e., allow for coverage of unknown regions.

WORK COMPLETED

During the second year, several significant accomplishments have been done at SRI. First, SRI manufactured small batches of actuators required for the UXO legged robot. As part of this project, the largest batch production of the EAP muscles was undertaken. SRI fabricated a total of 100 of the two layered double bowtie muscles. They accomplished this in a period of about 10 days. The process was robust enough to yield actuators that were within the15-20% performance tolerance.

The next accomplishment is that SRI built the whole body dynamic simulation of the six legged robot. Figure 1 shows a picture of a whole body dynamic simulation of the six legged robot. The simulation considers the dynamics of the limbs, the physical models of the muscle actuators, and simple friction models for the locomotion terrain.

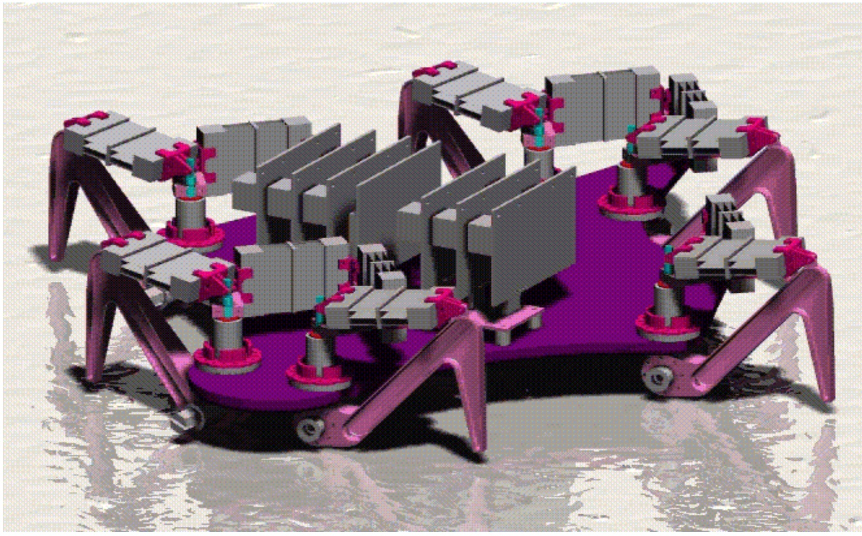

Figure 1. Dynamic simulation of a six legged robot

SRI also completed a two jointed single leg demonstration. Figure 2 below is a picture of a fully functional single leg with the muscle actuators. Each joint is driven using three double bowtie muscles in parallel. The muscles are actuated at 6kV. The electronics used for the demonstration consisted of breadboarded circuits and a standard video recorder battery.

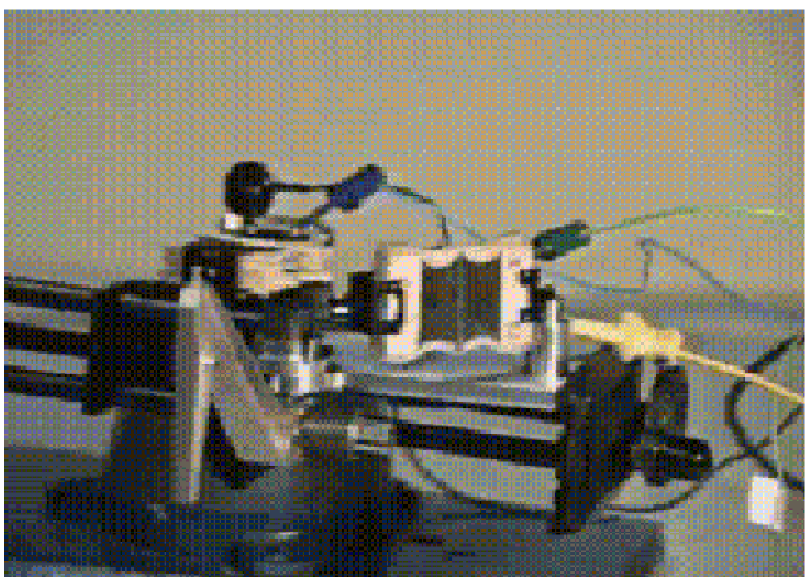

Figure 2. Single leg demonstration

Figure 3 shows a completion of the six legged robot called FLEX with onboard electronics, and onboard power. The interface electronics are fully functional, and the robot appears to run for several minutes using the onboard battery. However, the robot exceeded the mass budget by about 100 gms, and currently weighs a little over 600 gms. The system currently suffers from two problems. First, muscles (as they exist currently) do not appear to be strong enough to reliably move a robot that weighs 600 gms. To overcome this, SRI is in the process of trying four double bowtie actuators in parallel (instead of three). Second, variations in the muscles appear to be significant enough to impact the overall system performance. SRI will address this in the next muscle production cycle.

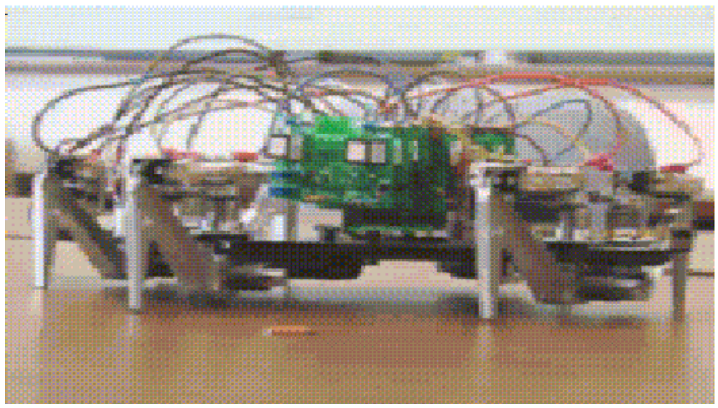

Figure 3. Hexapedal walking robot

At the same time, Apple Aid has developed a detection technology which allows a very low cost manipulator to pick up a piece of UXO in unstructured outdoor environments. The initial environment is a grassy surface lit by natural sunlight. Apple Aid breaks the problem into two parts, the determination of the position and pose of the UXO and the actual grasping and pick up of the UXO.

During FY 2000, CMU finished all of the derivations required for complete sensor based coverage of an unknown region and implemented it on an indoor mobile robot equipped only with simple and inexpensive range sensors. This algorithm differs from prior coverage work in that, barring positioning error, it is guaranteed to cover a target region and does not make any unrealistic assumptions like the target region can be represented by a fine resolution grid (of pixels). Experiments with the mobile robot clearly point to the need for good positioning algorithms.

RESULTS

As a result of the work completed during the second year, SRI now has a fully functional hexaped robot test bed. The robot is completely driven using onboard batteries. This is a feature that was not stated as a delivery during the second year, but was accomplished as part of their efforts. Initial testing on the next generation muscles that would function at twice the performance levels achieved during year two is already underway. Based on these tests, we hope to have an improved actuator design in the next fiscal year.

AppleAid demonstrated the successful operation of their system in June 2000 at NAVEODTECHDIV. The system was able to see a Rockeye submunition lying on the ground in front of it, determine the position and pose of the submunition, and pick it up. During testing at their facilities prior to the June

2000 demonstration, they measured a pick up rate for the system in the 90% range. During testing at NAVEODTECHDIV (in the days just prior to the demonstration), the pick up rate was measured in the 50-70% range. Failures were due to several factors, most notably the much brighter sun light observed during testing at NAVEODTECHDIV. The bright light overpowers the dynamic range of the inexpensive cameras they are using, causing errors in processing. They have subsequently added polarizing lenses to the cameras which appear to have solved the problem

IMPACT/APPLICATIONS

Legged locomotion for small robots shall result in greater mobility in unstructured terrain. The primary limitation preventing practical, low-cost, walking robots from being produced today is actuator technology. The application of artificial muscle materials in direct-drive actuators will have significant impact on future development of robots. It will allow for the realization of a new generation of ground robots that will possess improved maneuverability and mobility.

FLEX is the first free standing legged robot that is fully actuated using artificial muscles. Its design is inspired by the kinematics of the American cockroach, and as a result provides an excellent test bed for the investigation and integration of biologically inspired methods of actuation and control. Both the actuators developed and implemented, and the robot test bed constructed this year will have a significant impact in the research community. As SRI improves the performance of FLEX, its impact within the DoD community will be evident as well.

TRANSITIONS

This technology will be transitioned to conventional Joint Service EOD programs for the development of small robots for EOD applications, such as the Basic UXO Gathering System (BUGS). Other applications for small mobile robots will also be potential transitions, such as Surf Zone Mine Countermeasures. In addition, the technology might have a significant impact on DARPA programs such as Biomimetic Systems.

RELATED PROJECTS

In FY97 SRI began a separate project funded by NSF to develop a small, quadrupedal robot. The control research conducted within the NSF project will directly impact the control algorithms developed under the current contract.

SRI is also funded by ONR to apply the EPAM technology to the actuation of a dexterous hand. The muscle testing conducted under this ONR project and the current contract is synergistic.

AppleAid is also funded by ONR to examine the guidance of manipulators by use of visual cues. Their participation in this project is a concrete application of this research.

CMU has also started to apply their coverage work to car painting with Ford Motor, Inc.

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